Use of Landfill Leachate to Generate Electricity in Microbial Fuel Cells

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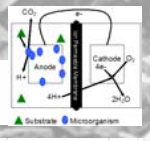
Introduction

Microbial fuel cells (MFCs), in which microorganisms catalyze the transfer of electrons released from the oxidation of organic compounds onto an electrode, are a promising biotechnological approach for harvesting energy in the form of electricity from certain wastes. The main purpose of this study was to determine if landfill leachate is a productive source of substrate and microbes for generating electricity in microbial fuel cells. Leachate is created when infiltrating rainwater dissolves contaminants within the landfill waste and seeps out the bottom of the landfill cell into a leachate collection system.

Microbial Fuel Cells (MFCs) consist of an anode, cathode, ion-permeable membrane separating the compartments containing the two electrodes, external circuit to utilize the energy, and the microorganisms.



MFCs are currently small and have been tested on a laboratory scale only. The technology is in its infancy and works on the basis of redox chemistry.

Materials and Methods

Four acrylic, two-chambered MFCs were used. The cathode and anode were graphite plates. A two-square-inch proton-permeable Nafion 117™ membrane was used for the proton transfer, required to complete the electrical circuit. The anodic compartment was filled with 400mL of landfill leachate as the substrate and source of microorganisms, and the headspace area of the anodic compartment was flushed with the CO_2 prior to capping to initiate and maintain anaerobic conditions. The cathodic compartment was filled with 400mL KH_2PO_4 salt buffer solution, and was continuously sparged with oxygen. The voltage between the electrodes was monitored across a 1000 ohm resistor, and data were continuously logged to the laboratory computer.

Objectives

- Determine whether landfill leachate contains electrochemically active microorganisms capable of generating electricity
- Study the possible application of MFC technology as a landfill leachate waste treatment alternative
- Determine which consortia of microorganisms contributed more to the voltage output: microbes attached to the electrode or suspended microbes
- Design a conceptual large-scale system for the SWACO Franklin County Landfill leachate system

Acknowledgements

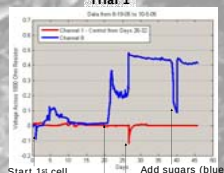
Various forms of support for this project were provided by:

- Ohio State Chapter of Sigma Xi - funding
- Undergraduate Student Government (USG) - funding
- Department of Food, Agricultural, and Biological Engineering – laboratory space
- OSU College of Engineering - scholarship
- Bio-Environmental Design Team (BEDT) - equipment
- Dr. Ann Christy, Dr. Olli H. Tuovinen, Dr. Rashmi Gaur, and Hamid Rismani-Yazdi - guidance

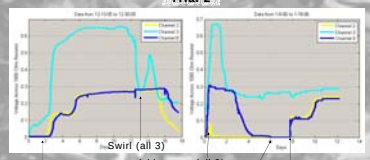
Results

Compared to the control which used autoclaved leachate and produced negligible voltage, fresh leachate produced about 0.120 volts (see Trial 1). The addition of 10 mL of a 0.4% soluble sugar mixture (0.1% each of glucose, cellobiose, maltose, and xylose) provided enough food source for the microorganisms in the leachate to generate electrical voltage that was nearly three times the amount produced without the sugar mixture (see Trial 1). Furthermore, this maximum voltage generation (0.450 volts) continued for nearly two weeks, over twice the length of generation for the leachate without sugar (see Trial 1). A second addition of sugar yielded similar results (see Trial 1) and over multiple trial runs (see Trials 2 and 3). The addition of leachate to a cellulose medium did not produce any visible changes; thus, the leachate bacteria cannot degrade cellulose. Further results indicated that these electricity-producing microbes reside on the graphite anode, as opposed to being suspended throughout the leachate fluid. This was determined when established anode graphite plates placed into autoclaved leachate anolyte produced more favorable responses than those from the established anolyte with new electrodes (see Trial 4). Additionally, leachate Chemical Oxygen Demand (COD) levels were reduced in initial tests after fuel cell electrical generation was complete (see COD Results Graph); the Five Day Biochemical Oxygen Demand (BOD5) results, however, were inconclusive between two test rounds (see BOD5 Results Graph).

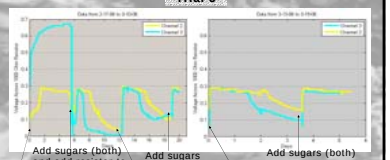
Trial 1



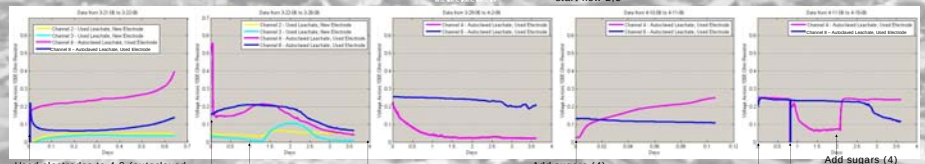
Trial 2



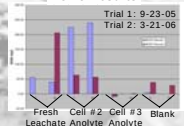
Trial 3



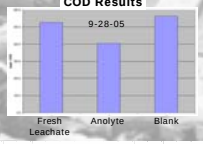
Trial 4



BOD5 Results



COD Results



A proposed large-scale MFC design for a landfill leachate lift station. This design is for the Solid Waste Authority of Central Ohio (SWACO), located near Grove City. Leachate used in this project came from the main lift station at SWACO. This design utilizes the principles of a single chamber, continuous flow MFC with air cathode. It incorporates 8-0.5 inch thick x 3.5 feet tall flat graphite plates (anode) with a 6 inch tall x 4 feet long rectangular cutout on the bottom for fluid movement. The plates are arranged 1 foot apart in a 8.5 foot diameter tank, with a circular piece of Styrofoam on top with a circular section removed to allow air to reach the graphite plate beneath it (air cathode).

S.T tank	h^2	m^2	in^2	Graphite Gasket Cost $0.12/sqin.	Lab Data Max Power Produced (kW*hrs) 24.197 mW/m^2 for 1 year of production	Lab Data Annual Power Value ($) at $0.0826/kW-hr	Lab Data Payback Period (years) at 4% interest	Highest Reported Power Produced (kW*hrs) 3600 mW/m^2 for 1 year of production	Highest Reported Annual Power Value ($) at $0.0826/kW-hr	Highest Annual Payback Period (years) at 4% interest
anode	318.00	29.547	24624.00	$2,954.88	6,222	$ 0.52		529,121	$ 76.93	
	4.00	0.372		$ -	0.079	$ 0.01		11,667	$ 0.97	
cathode	56.75	5.272	8171.28	$ 980.55	1.119	$ 0.09		165,796	$ 13.73	
beam	8.94	0.747	576.00	$ 69.12	0.157	$ 0.01		23,496	$ 1.96	
total	386.78	35.934	33371.28	$4,004.55	7.568	$ 0.63	(141.65)	1,130,099	$ 93.57	(35.64)

$0.0826/kW according to U.S. Dept. of Energy, January 2004 average electricity cost

Power Production and Cost Analysis with Payback Periods

Conclusions and Future Work

Microbial fuel cells were proven to be able to generate electricity directly from landfill leachate via naturally-occurring microorganisms in the leachate. The addition of a 0.4% soluble sugar mixture significantly increased voltage values, indicating that the leachate may lack enough carbon sources to support long-term batch fed electrical generation. However, since the conceptual large-scale application of MFCs to landfill leachate lift stations would involve continuous flow of influent leachate, a steady supply of carbon may be provided. Lab-scale testing with continuous flow, single chamber air cathode MFCs should be performed before this design is implemented. Further testing with leachate from different landfills, as well as with methods to optimize electrical production, should also be performed. COD results indicate that MFCs are potentially effective in treating landfill leachate; more COD tests need to be performed to verify this possibility. Further microbiological tests (i.e., plating out the bacteria) need to be performed to help identify these bacteria. A cost analysis of the conceptual design yielded a range of estimated power density outputs and the resulting cost savings and payback periods. These high payback periods indicate that MFC technology is not mature enough to justify the implementation of this design based on economics alone; however, as energy costs continue to rise and MFC power production is maximized, MFCs could become more feasible.